A NEW SYSTEM FOR MEASURING FREQUENCY

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ABSTRACT

Making frequency measurements traceable to the National Bureau of Standards (NBS) has traditionally been a problem for calibration laboratories. There are several methods for doing this, including the use of WWV, WWVB, and Loran-C receivers, but each method has its drawbacks. One drawback is that users often have only the manufacturer's instruction manual for support to assure them that their equipment is working, and sometimes different pieces of equipment don't work well together.

Another drawback is that some kinds of equipment require a considerable amount of time and skill to operate. And finally, even if the calibration laboratory has the time and the skill to devote to the problem, the data obtained are often in a format that is difficult to interpret. Using such an approach, each user gets data in a different format.

The Time and Frequency Division of the National Bureau of Standards has addressed each of these problems by introducing a new NBS Frequency Measurement Service. The service has been in operation for over one year and provides state-of-the-art frequency measurements traceable to the National Bureau of Standards with a minimum of effort on the part of the user.

This paper provides an overview of the NBS Frequency Measurement Service. It begins by discussing the basis for the new service, and the equipment supplied with the service. It shows the advantages of the output data obtained with the service. It explains how the system works and discusses accuracy, reliability, and ease of use. The paper also discusses how the NBS supports the service with training, on-line diagnostics, published measurement data, and monthly performance reports.

BASIS FOR THE NEW SERVICE

No one questions that calibration laboratories need a good on-line frequency source. The source should have sufficient accuracy to meet the needs of the lab's customers, and should not require an inordinate amount of time and effort to operate. Removing the frequency source from service and sending it to the National Bureau of Standards or elsewhere for calibration is impractical, since by their nature, frequency sources are sensitive to shipment, and to being turned on and off.

To achieve calibrations at high levels of accuracy, labs need to back-up their primary frequency source with batteries, keep it running all the time, and continuously measure its performance. This becomes especially important when making calibrations at state-of-the-art accuracy levels, because even small phase shifts can change the results.

Continuously measuring the performance of a frequency source is important. It takes a long time to make a useful frequency measurement and sudden variations in performance can cause potentially serious losses in accuracy. The past performance of a frequency source is just as important as the present performance. The NBS recognized that labs needed a way to continuously measure and record the performance of their frequency standards and that this process should be automated as much as possible. With these things in mind, the NBS Frequency Measurement System was introduced.

THE EQUIPMENT SUPPLIED WITH THE SERVICE

Users who subscribe to the NBS Frequency Measurement Service receive a complete frequency measurement system at their laboratory. The users install the equipment using a detailed instruction manual. It requires mounting an eight-foot whip antenna on a rooftop location, putting the equipment in the supplied cabinet, and connecting a few cables. All of the equipment and cables needed for installation are supplied.

The assembled system is about the size of a component stereo system and can easily fit on a desktop or a small table (see figure 1, page 3). It consists of a computer with two disk drives and a monitor, a frequency divider, a time interval counter, a Loran-C receiver, and a printer. A telephone modem and a time-of-day clock are inside the computer. The modem provides the National Bureau of Standards with access to the data and the clock provides the required data timekeeping functions.

WHAT THE FREQUENCY MEASUREMENT SYSTEM DOES

The frequency measurement system is an automated data acquisition system that measures and records the performance of from one to four frequency sources. It is designed to run 24-hours a day, and will restart automatically after power outages. Once each day, the frequency measurement system makes a printed plot for each oscillator being measured (see Figures 2 and 3, page 4).

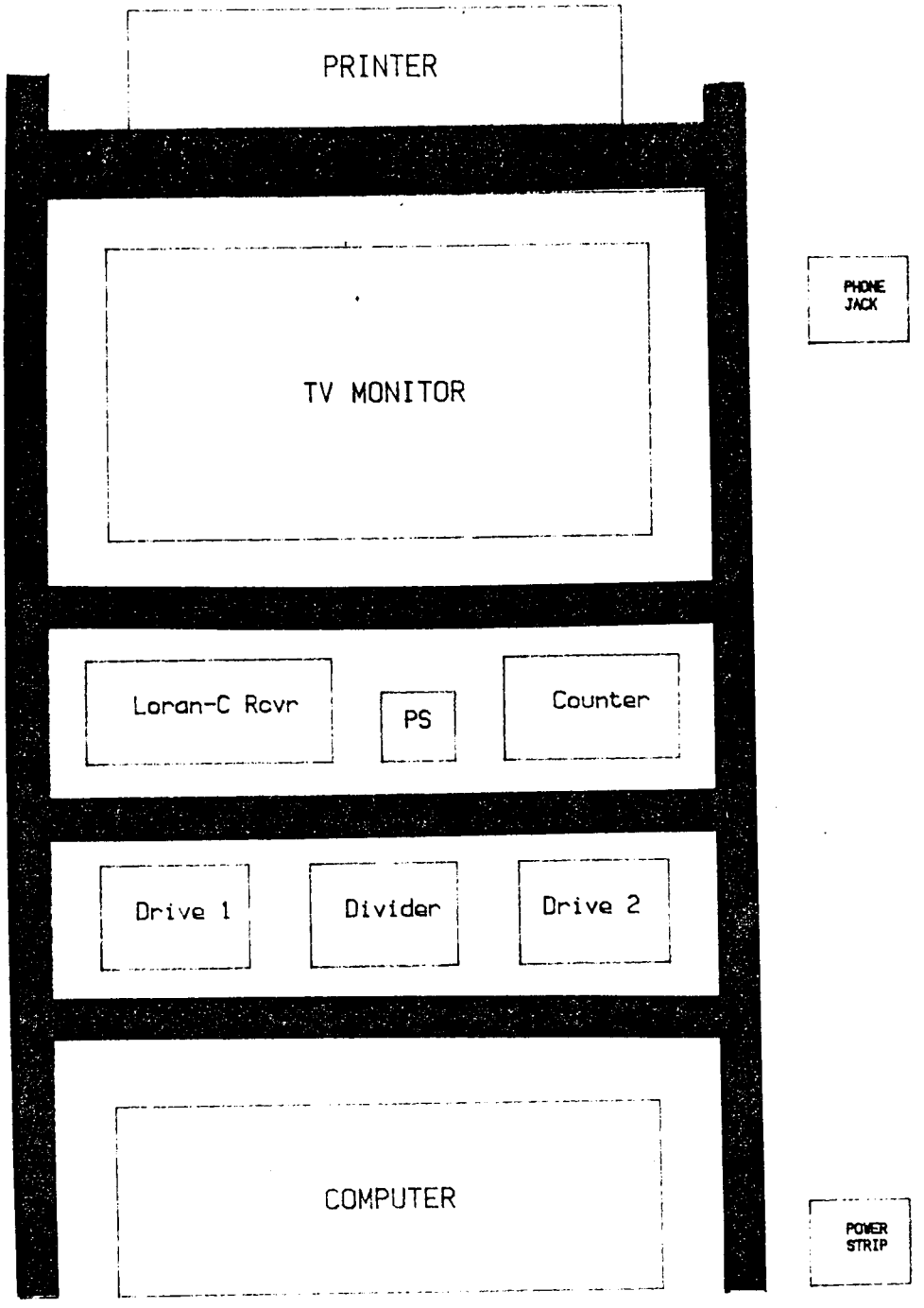


Figure 1 - Physical Layout of the NBS Frequency Measurement System

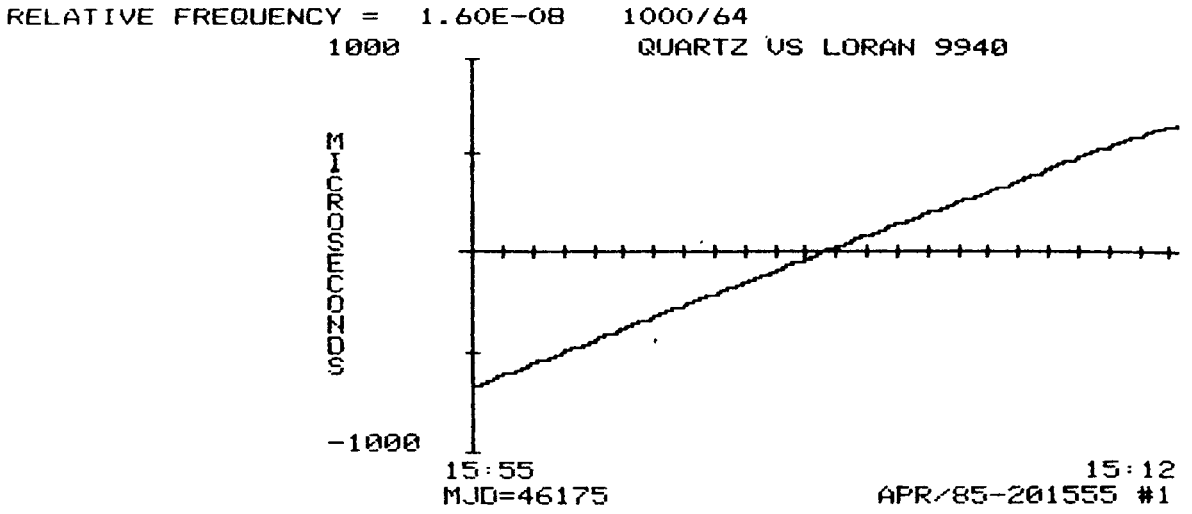


Figure 2 - Phase plot of low-quality quartz oscillator

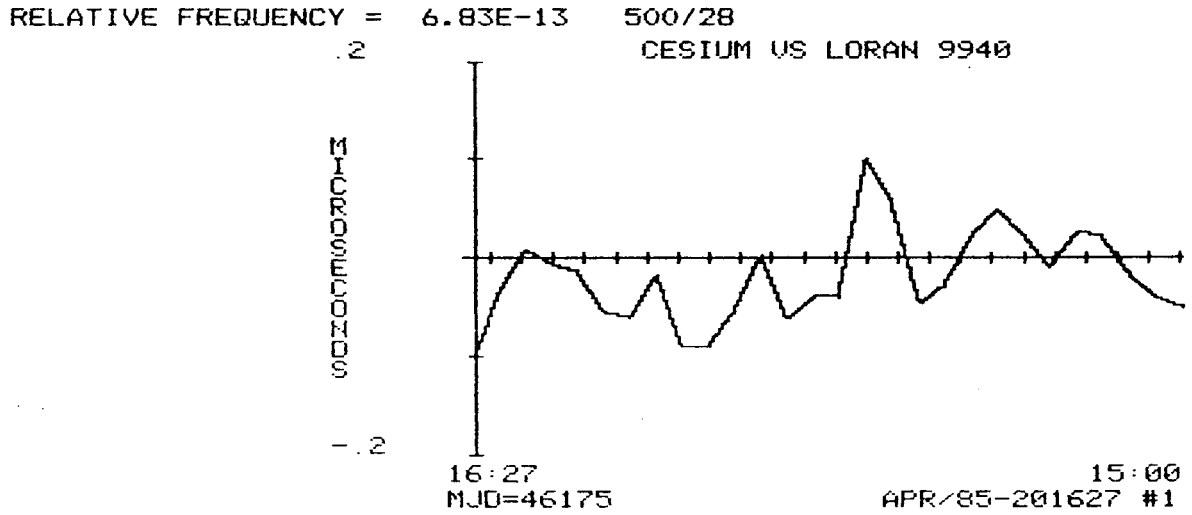


Figure 3 - Phase plot of cesium oscillator

The data are printed in a way that is easy to understand; as oscillator phase shift versus time of day. Each day's plot can be laid next to the plot from the previous day and is scaled to compensate for the amount of oscillator drift. The relative frequency of the oscillator being measured is printed on the phase plot. Since the system can adjust the Y-axis, it can show relative frequency offsets as small as 1 part in ten to the fourteenth, or as large as one part in ten to the fifth. This lets the system measure everything from low cost frequency counters to precision atomic oscillators.

HOW THE FREQUENCY MEASUREMENT SYSTEM WORKS

The frequency measurement service makes time interval measurements between two signals of the same frequency. One of these signals is a Loran-C reference frequency and the other is the oscillator being measured (see Figure 4, page 6). The time interval counter supplied with the frequency measurement service can measure the performance of four oscillators simultaneously. Channel one is dedicated to the calibration of the main or the primary oscillator in the calibration laboratory. The performance of this primary oscillator is checked regularly by the NBS for traceability.

Once signals are connected, users of the service can just wait for the daily plots. The computer reads the counter (measurements are made with 10 nanosecond resolution), records and averages the measurements, and stores the averaged data on disk along with the time of day when the data were recorded. Once each day, the system stops taking measurements and plots all of the data accumulated in the last 24 hours. Measurements are then resumed and the process continues, recording, plotting, recording, plotting, etc. The only operator attention required is to occasionally change the data disk or to add paper to the printer.

ACCURACY OF THE SERVICE

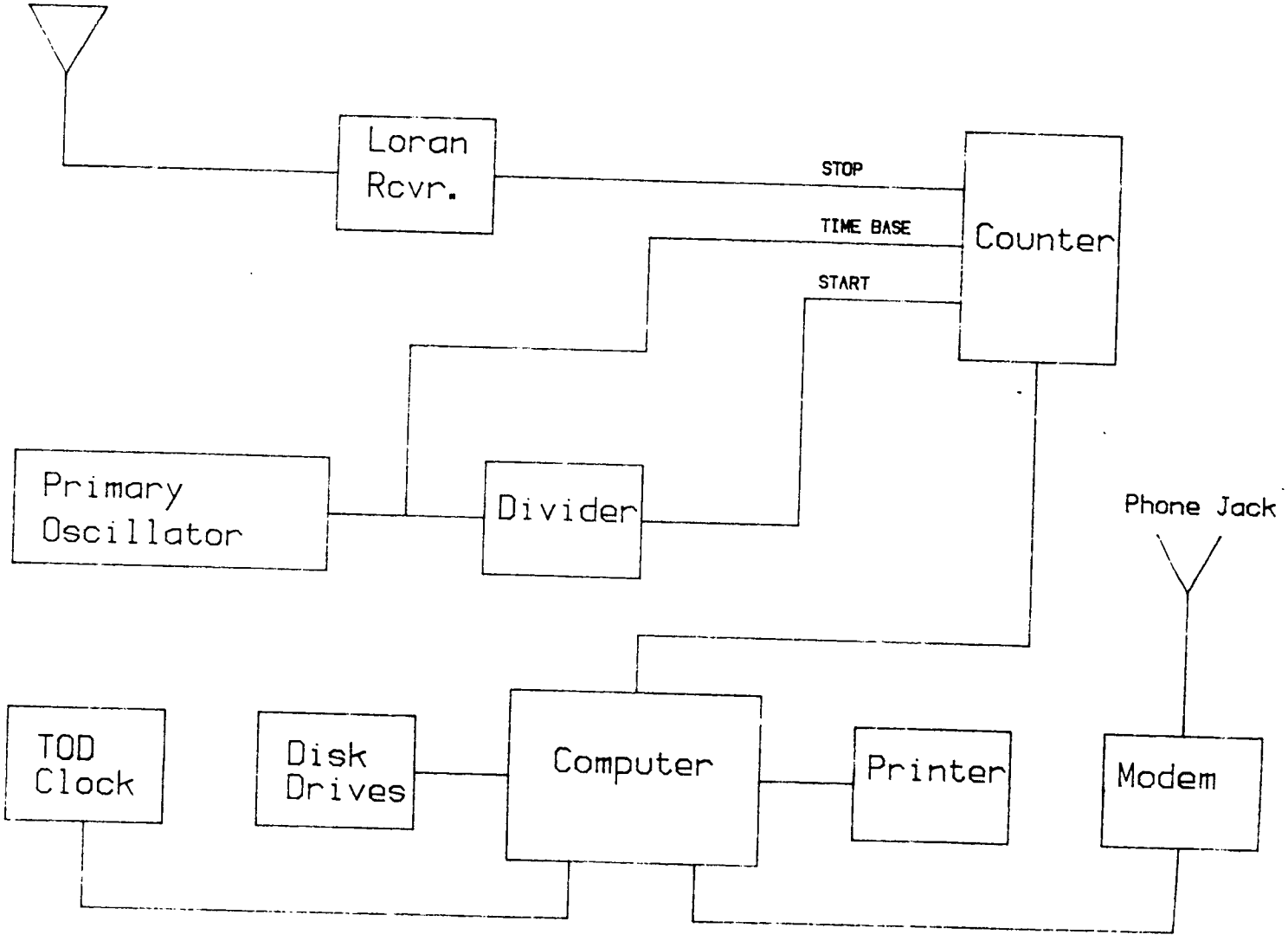
Loran-C was chosen for the service for several reasons. It provides an extremely stable frequency at a low cost, it is traceable to the NBS, and it provides full coverage of the United States. Each Loran-C station is controlled by cesium standards monitored by both the U.S. Coast Guard and the Naval Observatory. Loran-C typically provides a frequency stability of a few parts in ten to the 12th over a 24-hour period. This is good enough to check the performance of cesium oscillators and to calibrate any rubidium or quartz oscillator.

RELIABILITY AND EASE OF USE OF THE MEASUREMENT EQUIPMENT

The reliability of the measurement equipment is good. Each individual system is tested at the NBS for at least one month prior to shipment.

The system also makes it easier to make calibrations. The plots made by the system show the user how far off frequency each oscillator is and which way it is drifting. A moderately priced oscillator can be adjusted until its performance matches that of a much costlier unit. The equipment automation lets users concentrate on calibrations, and not on the day-to-day operation of the equipment.

Figure 4 - BLOCK DIAGRAM OF NBS FREQUENCY MEASUREMENT SYSTEM



NBS SUPPORT

Training

The NBS training provided to subscribers of the service covers the operation of the frequency measurement service and frequency calibrations in general. Each subscriber to the service attends a frequency measurement seminar in Boulder, Colorado. These seminars are limited to small groups and provide actual hands-on training with the equipment. The seminars give users a chance to ask questions about specific applications they have in their own organizations.

On-line Diagnostics

Using the telephone modem, the NBS interrogates each frequency measurement system and checks it for correct operation. This is done at least once per week and more often if needed. The NBS can do nearly anything from the remote terminal that can be done locally, and thus can identify and resolve most problems that arise.

Published Data

The NBS monitors the United States Loran-C chains, as well as other time and frequency broadcasts, and publishes the results both in the monthly Time & Frequency Bulletin, and in a special report mailed to users of the measurement service. The U.S. frequency standard is used as the basis for these measurements. Loran-C phase variations are usually very small, but the published data gives users a traceable record.

A monthly report is sent to each user of the service showing the frequency history of the user's primary oscillator over the past month. The report lists Loran-C phase shifts, days when data were not recorded by the system, and other information pertaining to the user's frequency measurements. This report allows each user of the service to certify that their measurements are traceable to the National Bureau of Standards.

Improvements to the Service

Improvements to the NBS Frequency Measurement Service are made whenever necessary. These include upgrades in hardware, software, documentation, and training materials.